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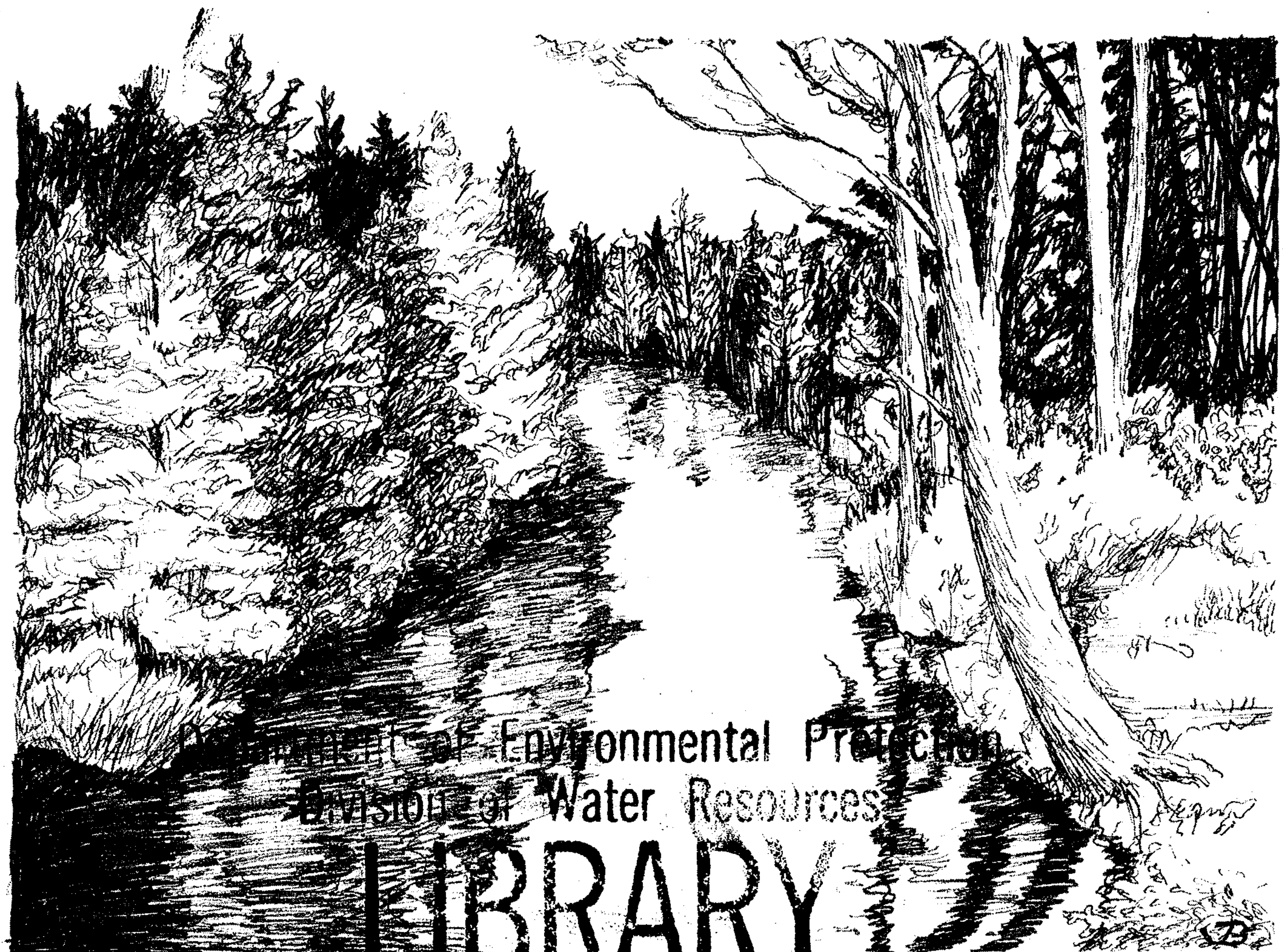
INVESTIGATION OF ACIDITY AND OTHER WATER-QUALITY CHARACTERISTICS OF UPPER OYSTER CREEK, OCEAN COUNTY, NEW JERSEY

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 80-10



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Water-quality data collected in the upper Oyster Creek drainage basin indicate that the stream has excellent water quality except for a persistently low pH. The mean concentrations of the major inorganic ions were all less than 6.0 mg/L. Mean concentrations of total nitrogen and total phosphorus were 0.15 mg/L and 0.01 mg/L, respectively. Dissolved oxygen averaged 8.7 mg/L and 81 percent saturation.

Low pH levels are typical of streams draining cedar swamps. In Oyster Creek, the pH tended to decrease downstream due to chemical and biological processes. The pH levels in swamps were one-half unit or more lower than the pH levels in the adjacent stream.

Sharp declines in stream pH were noted during runoff periods as the result of the mixing of poorly-buffered stream water with more highly acidic water from surrounding swamp areas.

The quality of ground water within the study area was similar to the quality of streamflow, except for higher iron and ammonia-nitrogen concentrations and a higher pH range of 4.9-6.5. Precipitation represented a major source of many chemical constituents in the ground- and surface-waters of Oyster Creek basin.

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INVESTIGATION OF ACIDITY AND OTHER WATER-QUALITY CHARACTERISTICS OF UPPER OYSTER CREEK, OCEAN COUNTY, NEW JERSEY

By Thomas V. Fusillo, James C. Schornick, Jr., Harry E. Koester, and Douglas A. Harriman

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July 1980

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting inch-pound Units to International System (SI) Units

Multiply inch-pound units	by	To obtain SI units
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4047	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
pound (lb)	0.454	kilogram (kg)

ABSTRACT

Water-quality data collected in the upper Oyster Creek drainage basin indicate that the stream has excellent water quality except for a persistently low pH (median 4.5).

The mean concentrations of the inorganic ions were all less than 6.0 milligrams per liter. Mean concentrations of total nitrogen and total phosphorus were 0.15 and 0.01 milligrams per liter, respectively. Dissolved oxygen averaged 8.7 milligrams per liter and 81 percent saturation.

Low pH is typical of streams draining cedar swamps. Within the study area, pH tended to decrease downstream due to chemical and biological processes. The pH in swampy areas was half a unit or more below the pH in the adjacent stream.

Sharp declines in stream pH were noted during runoff as the result of the mixing of poorly buffered stream water with more highly acidic water from surrounding swamp areas. These pH declines severely hinder brook trout survival due to the toxic effect of highly acidic water.

The quality of ground water was similar to the quality of streamflow, except for higher iron and ammonia-nitrogen concentrations and a pH range of 4.9 to 6.5. The highest concentrations of most chemical constituents were found in the ground water within the organic muck beneath swamp areas.

The quality of precipitation on the area was also similar to the quality of streamflow. The pH of precipitation ranged from 4.2 to 7.0. Precipitation represents a major source of many chemical constituents in the water of the Oyster Creek basin.

INTRODUCTION

The rapid increase in recreational fishing in New Jersey and the growing pressure on freshwater fisheries make it desirable to expand current trout-stocking programs of the streams in the outer Coastal Plain of New Jersey. These streams appear to be well suited to supporting trout; they have cool temperatures, sufficient dissolved oxygen, and are relatively free of pollution. One unfavorable characteristic of these streams, however, is a very low pH, even for trout waters. The pH of most coastal-plain streams averages between 4.0 and 5.0 (Rhodehamel, 1970). Rapid drops in pH to below 4.0 have been observed during runoff; under these conditions trout survival is affected.

Preliminary investigations during the 1950's (Pyle, 1957) involved survival experiments with brook trout, Salvelinus fontinalis, brown trout, Salmo trutta, and rainbow trout, Salmo irrideus, in various streams of the outer coastal plain of New Jersey. These experiments indicated that brook trout is the most acid-tolerant species, capable of surviving in streams with pH as low as 4.3. Brown trout and rainbow trout did not survive in streams with pH below 5.0 and 5.9, respectively, and were considered unsuitable for stocking in the more acidic streams. As the pH of most coastal-plain streams falls below 4.3 for at least brief periods during the year, even brook trout may not survive.

Brook trout were stocked experimentally in Oyster Creek, Ocean County, during the 1950's and 1960's. The creek provides good trout habitat, except for its low pH. The flow is fairly uniform throughout the year, with ground-water inflow maintaining high water levels even during the summer. The water temperature in the creek is moderated by ground water, causing cooler temperatures than expected during the summer and warmer temperatures during the winter. The dissolved oxygen content of the water rarely falls below a concentration of 6.0 mg/L; and the overall water quality is excellent, with very low concentrations of dissolved and suspended materials. Thus, the low pH seems to be the major barrier to a successful trout-stocking program.

Acknowledgments

The authors are grateful for the cooperation received from the residents of Brookville, New Jersey. They also thank Mr. Clifford Oakley of Manahawkin, New Jersey, for permitting work to be done on his property.

Purpose and Scope

The U.S. Geological Survey, in cooperation with the New Jersey Department of Environmental Protection, Division of Fish, Game, and Shell Fisheries, made a study from 1968 to 1978 to assess the chemical quality of upper Oyster Creek. Emphasis was placed on monitoring pH and the chemical constituents that affect the pH of natural waters. This report includes streamflow and water-quality data collected at the gaging station, Oyster Creek near Brookville, between 1965 and 1977 as part of the statewide stream-monitoring network, in addition to data collected specifically for this study. This report will present the data to aid in developing management techniques for brook trout in acidic streams and lakes.

DESCRIPTION OF THE PROJECT AREA

Oyster Creek is located in the Pinelands along the east-central part of New Jersey's outer Atlantic Coastal Plain in southern Ocean County. Its drainage area is 12.9 mi² at the mouth of Barnegat Bay. This study includes only a 7.43 square-mile area in the upper part of the basin above the U.S. Geological Survey surface-water gaging station No. 01409095, Oyster Creek near Brookville. The location of the study area is shown in figure 1.

Oyster Creek flows over the Cohansey Sand for most of its length. Most soils in the watershed are poor, thin, and deficient in fertility due to the rapid leaching of nutrients. The creek flows through many bogs, ponds, and swamps. The basin contains several cranberry bogs, although cranberry farming has nearly ceased on Oyster Creek because of interference caused by recreational activities.

Geology and Soils

The Cohansey Sand which underlies most of the outer coastal plain, is approximately 150 ft deep in the area of Oyster Creek. The contact between the Cohansey Sand and the underlying Kirkwood Formation dips to the south-southeast at approximately 10 ft/mi (Rhodehamel, 1973). The Cohansey Sand is of Miocene age and is characteristically a yellow-brown fine to very coarse quartz sand that is locally cemented with iron oxide. White, dark-gray, and red kaolinitic clay deposits are interbedded with the sand beds (Anderson and Appel, 1969).

The soil types that overlie the Cohansey Sand within the Oyster Creek basin are largely sands and sandy loams, averaging 10 ft in depth. They are low to moderate in fertility and available water capacity and have rapid permeability, except where interbedded with clay. These soils are typified by strongly acidic soil reactions. The pH of the soil-water solution in the upper soil profile ranges from 3.6 to 5.5. The distribution of soil types is shown in figure 2.

The main stream channel of Oyster Creek and the surrounding swampy areas are underlain by the Manahawkin muck, a soil composed of finely divided organic material which is extremely acidic. Most of the tributaries to the main channel lie on the Atsion sand, a very sandy soil containing moderate to high amounts of organic matter. The Atsion sand has a seasonally high water table which is at the surface during wet seasons but may drop 2 to 3 ft during the summer. The Berryland sand forms the flood plains of

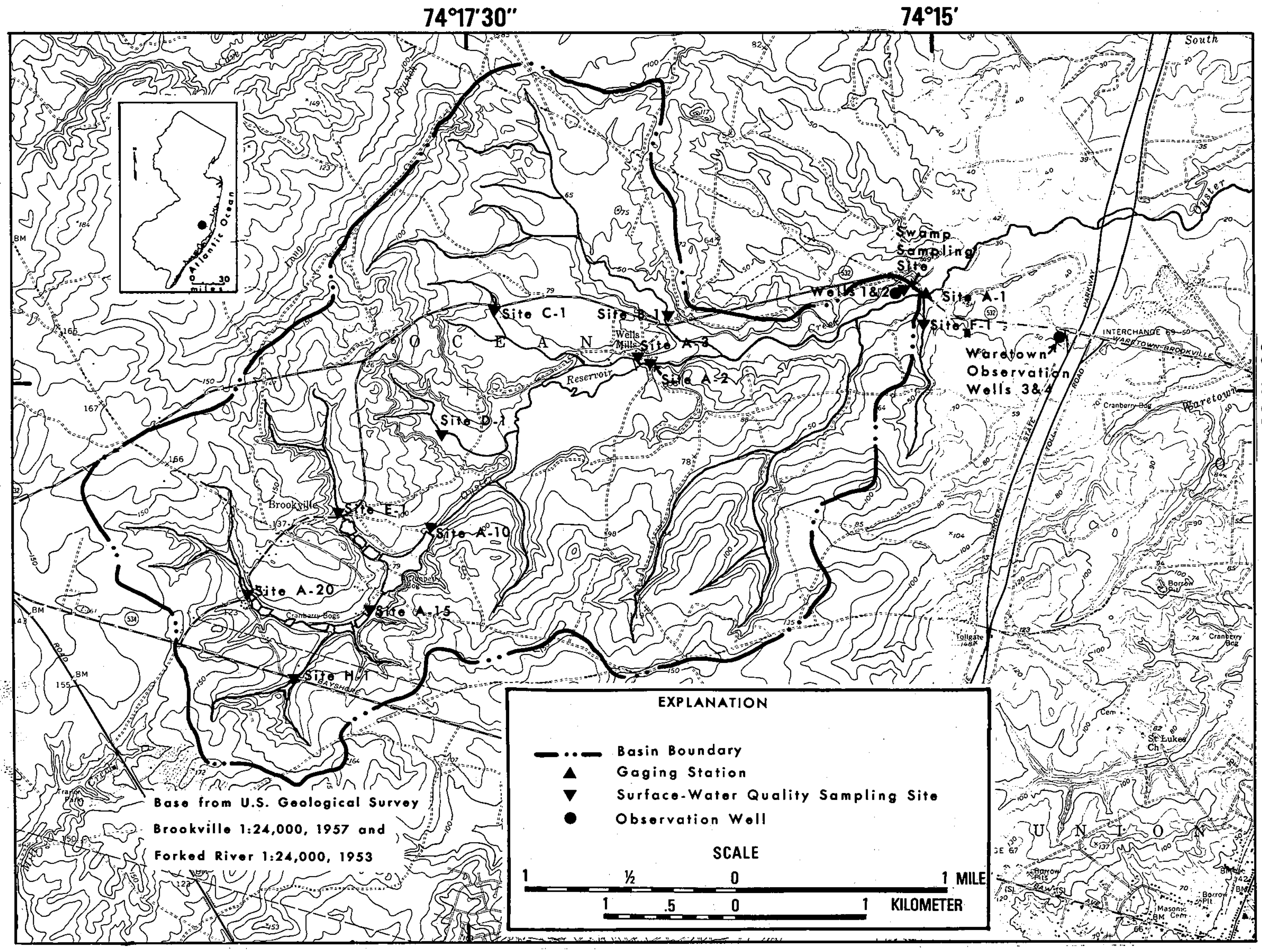


Figure 1.--Map showing data collection sites in Oyster Creek study area.

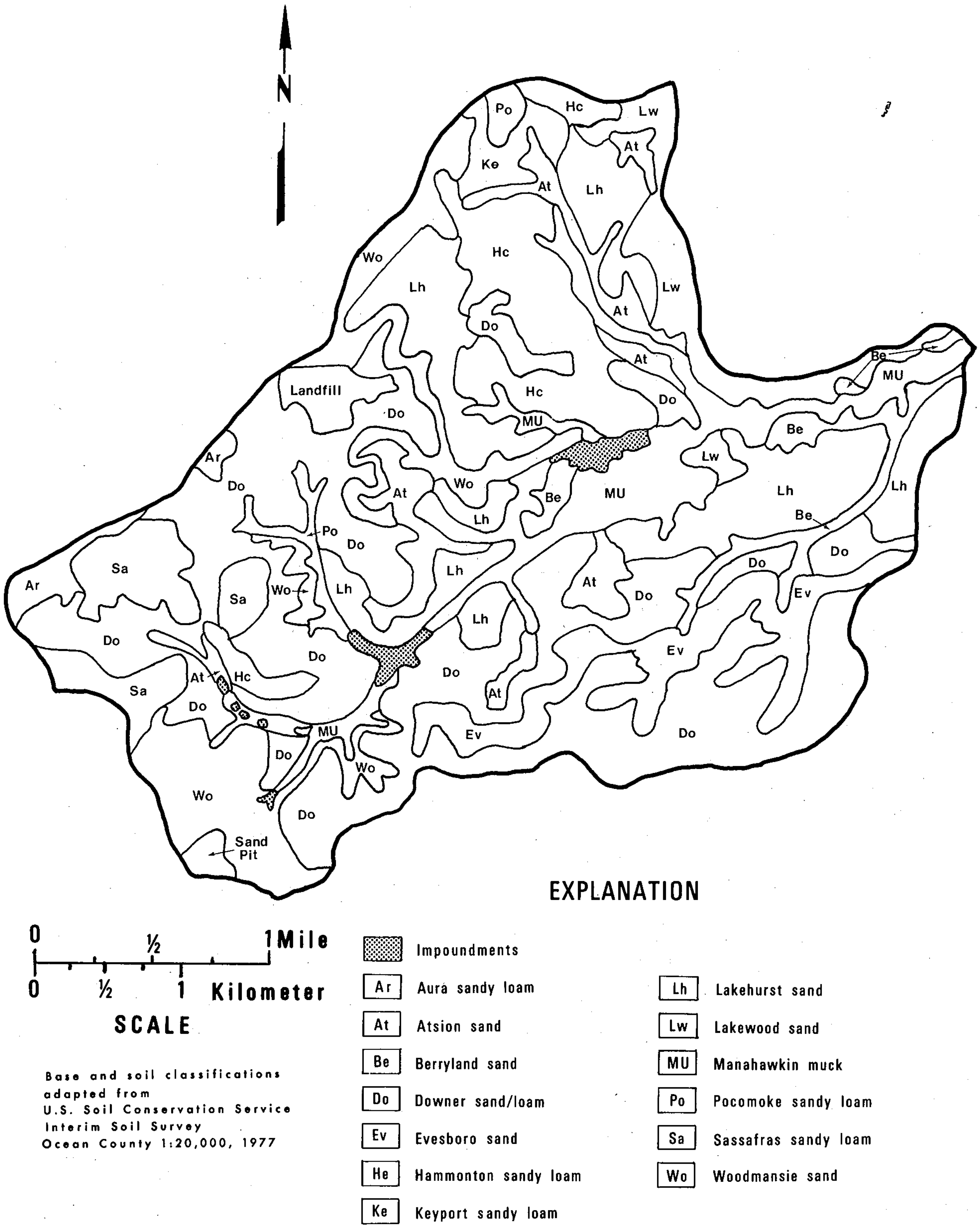


Figure 2.-- Map of soil types within upper Oyster Creek basin.

Oyster Creek, with a mucky surface layer and a sandy subsurface. Berryland soils also contain moderate to high amounts of organic material and may be frequently flooded. At higher elevations in the drainage basin are the Aura sandy loam, Downer sandy loam, Woodmansie sand, Lakehurst sand and Lakewood sand. These are all well-drained soils with a low productivity, although they support growth of mixed woodlands, including pitch pine and scrub, white, and black oak.

Climate

The Oyster Creek basin experiences a temperate, mostly continental, climate. The mean annual air temperature is 54° F (12° C), with a range in mean monthly temperature from 34° F (1° C) in January to 75° F (24° C) in July. Oceanic air masses intrude the land area in late summer, making July and August the wettest, warmest, and most humid months of the year. The average annual rainfall for the area is 45 inches, with the highest monthly averages in July and August, at 4.4 inches and 4.7 inches, respectively.

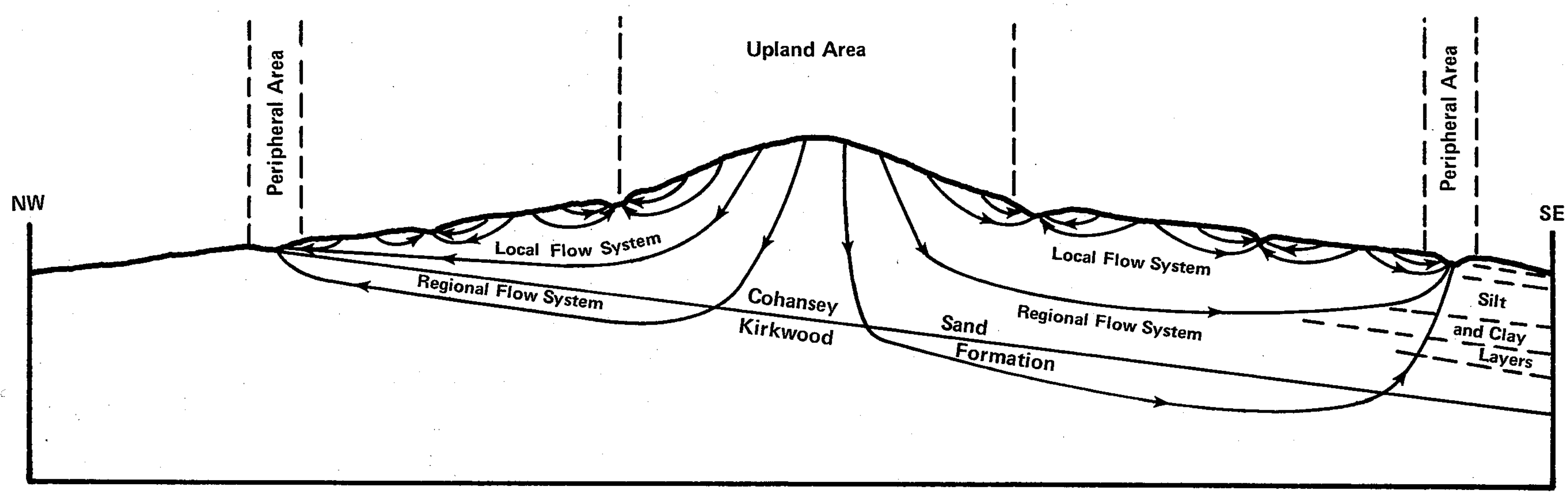
Hydrology

The hydrology of the Oyster Creek basin and most of the Pinelands region is strongly influenced by ground-water flow patterns. The sandy soils permit rapid infiltration of rainfall into the aquifer, and ground water constitutes an average of 89 percent of the total annual stream discharge within the Pinelands (Rhodehamel, 1970).

Oyster Creek is unique in having surface-water discharge greater than the precipitation the surface-water drainage basin receives. The mean annual discharge of Oyster Creek at the Brookville gaging station at site A-1 during the period 1966 through 1977 was 50.8 inches, while the mean annual precipitation over the same period was only 45.2 inches. Low-flow analysis (Gillespie, personal commun., 1979) shows that while Oyster Creek has excessive surface runoff, the nearby Oswego River and North Branch Forked River have much lower rates of surface runoff. Rhodehamel (1970) has described a regional flow system in the Pinelands in which recharge enters a shallow local flow system in the upland areas of the Cohansey Sand, bypasses some local streams, and discharges into more distant streams in the peripheral areas at lower altitudes. Oyster Creek, being a low-lying basin, may receive ground-water inflow from the Oswego River and/or North Branch Forked River basins. Figure 3 represents an idealized cross section showing ground-water flow patterns in the Pinelands region.

Land Use

The Oyster Creek study area lies within Ocean, Lacey, and Union Townships in Ocean County and is almost entirely undeveloped. Two county highways, routes 532 and 534, and several



(From Rhodehamel, 1970)

Figure 3.-- Idealized cross section showing ground-water flow patterns in the Pinelands region.

other improved roads pass through the basin. Unimproved roads and trails crisscross through the forested upland areas of the watershed. There is a small residential area consisting of several dozen homes at Brookville in the upper reach of the basin. Several cranberry bogs within the study are no longer commercially productive. The Brookville Boy Scout Reservation is located on one of the bogs and a private campground on another. Both utilize the bogs for swimming, boating, and fishing.

In the northwest part of the Oyster Creek basin is a sanitary landfill of approximately 40 acres. A sand and gravel pit is located along the drainage divide between Oyster and Mill Creeks in the southwest corner of the basin. The locations of the landfill and the sand pit are shown in figure 2.

Most of the Oyster Creek watershed is wooded, with white cedar predominating in the low-lying swampy areas. Sphagnum moss, swamp magnolia, mountain laurel, and various berries are also common in poorly drained regions. The more well-drained areas of the basin are forested with white oak and pitch pine, with a fairly dense undergrowth of brush.

DATA COLLECTION

The initial water-quality data collection began in 1968, with the installation of a strip-chart pH recorder at site A-1, the stream-gaging station Oyster Creek near Brookville, N.J. (See figure 1.) The strip-chart pH recorder was removed in November 1974 after numerous malfunctions and replaced in January 1975 by a four-parameter water-quality monitor (monitoring pH, specific conductance, temperature, and dissolved oxygen). After the collection of water-quality records, the monitor was removed in April 1977.

Weekly field visits were begun in January 1974 to complement the automatic data collection with the collection of pH data at site A-1 and an adjacent swamp, shown in figure 1. In November 1975, the field data collection was expanded to include additional sampling sites on the main stem of Oyster Creek and its major tributaries. Temperature and pH were measured in the field at six sites on the main channel and sites on seven tributary streams. Additional water-quality data were collected at these surface-water sites during two intense sampling periods, one on April 13, 1978, during baseflow conditions and the second on May 25, 1978, after a 3-inch rainfall. Specific conductance, pH, temperature, and dissolved oxygen were measured in the field. Samples were collected for the analysis of dissolved solids, total hardness, ferrous and total iron, sulfate, chloride, and total nitrogen.

Continuous streamflow records have been collected at the U.S. Geological Survey gaging station, Oyster Creek near Brookville, New Jersey (site A-1), since July 1965. Water samples for chemical analyses were collected periodically at the site from September 1965 to September 1977.

Ground-water levels in the Oyster Creek basin were monitored continuously at two observation wells. Well 1 was bored into the swamp deposits near the stream channel to a depth of 4 ft. Well 2 was bored through the swamp deposits adjacent to well 1 into the top of the underlying Cohansey Sand to a depth of 14 ft below the land surface. These wells were operated from August 1973 to June 1976. Water samples for chemical analysis were collected from these wells on December 5, 1974, and November 5, 1975. One of two local Waretown observation wells, which had been last sampled in 1962, was resampled in January 1977.

Monthly precipitation data for the period January 1966 to December 1977 were obtained from annual climatic data summaries of the National Oceanic and Atmospheric Administration (1966-77). Monthly precipitation at Oyster Creek was estimated by averaging the precipitation data for the official gages at Chatsworth, Toms River, and Tuckerton. In September 1976, a recording rain gage was installed in the watershed and operated until April 1977.

RESULTS

Streamflow

The streamflow in Oyster Creek is moderated throughout the year by ground-water inflow, resulting in a steady baseflow and infrequent serious flooding. The discharge hydrographs shown in figure 4 for water years 1975, 1976, and 1977 are all relatively flat, with few sharp peaks. The permeable, sandy soils within the basin promote rapid infiltration of rainfall into the ground-water system, reducing surface runoff. The rate of runoff is further reduced by water storage in the swamps. The mean discharge for the period of streamflow record at site A-1 is 27.8 ft^3/s, with maximum and minimum discharges of 232 and 12 ft^3/s.

The flow-duration curve for site A-1, which shows the percentage of time that discharges were equalled or exceeded during the period of streamflow record, is presented in figure 5. The flat slope of the curve shows the influence of surface-water and ground-water storage on the stream hydrology (Searcy, 1959).

Low-flow characteristics of a stream are commonly used to evaluate the adequacy of streamflow for maintenance of suitable conditions for fish (Riggs, 1972), since stress periods often occur during low-flow conditions. The low-flow frequency curves for Oyster Creek are shown in figure 6. They give the recurrence interval and probability of low-flow periods of duration from 1 to 30 consecutive days. These curves show that the 7-day, 10-year low flow, i.e., the average minimum flow for 7 consecutive days that is expected to occur on the average of 1 year in 10, is 16 ft^3/s or 2.15 $(ft^3/s)/mi^2$. This level of discharge during low-flow periods is sufficient for maintaining acceptable stream conditions for fish.

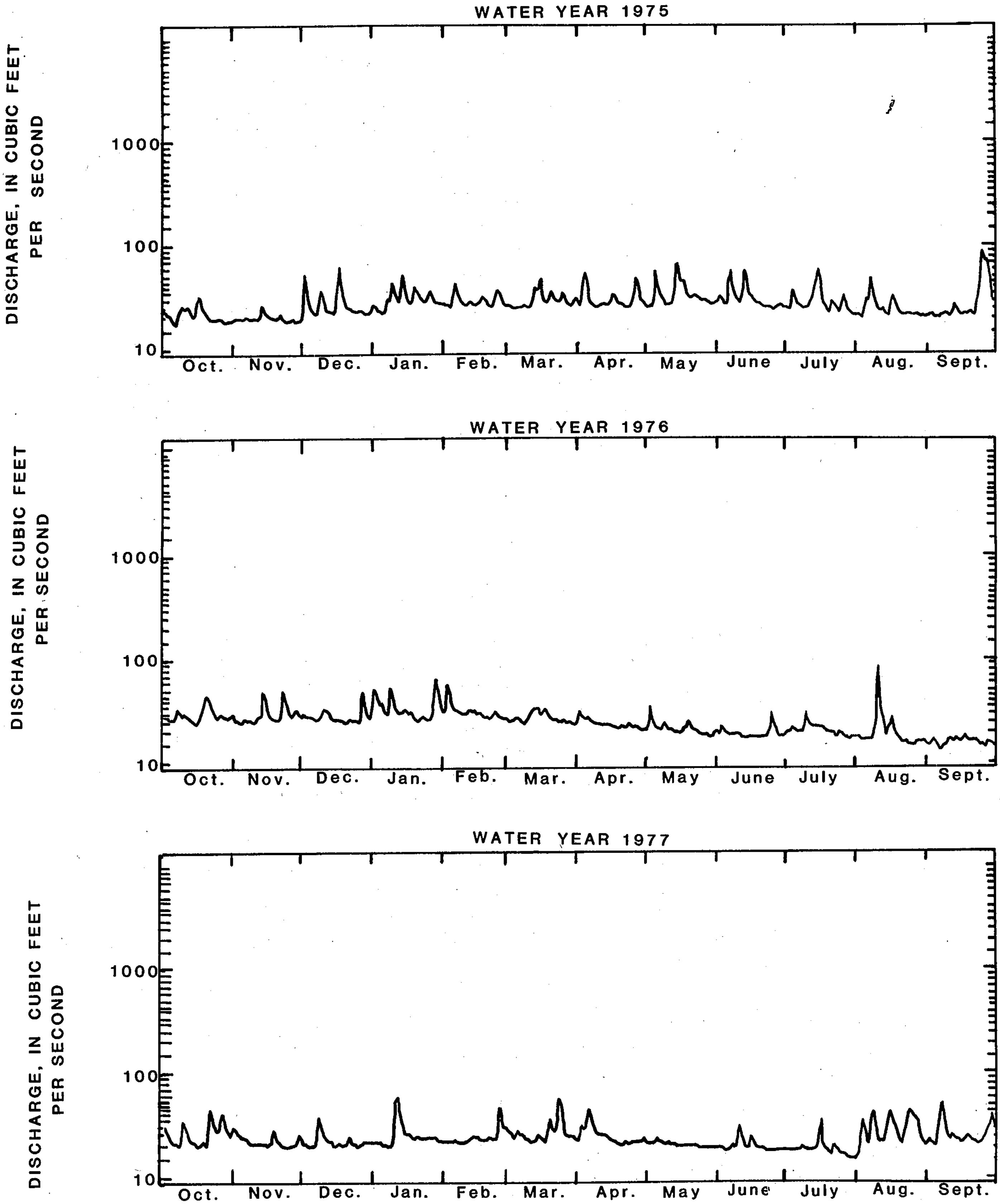


Figure 4.--Discharge hydrographs for site A-1, Oyster Creek near Brookville, New Jersey; water years 1975-1977.

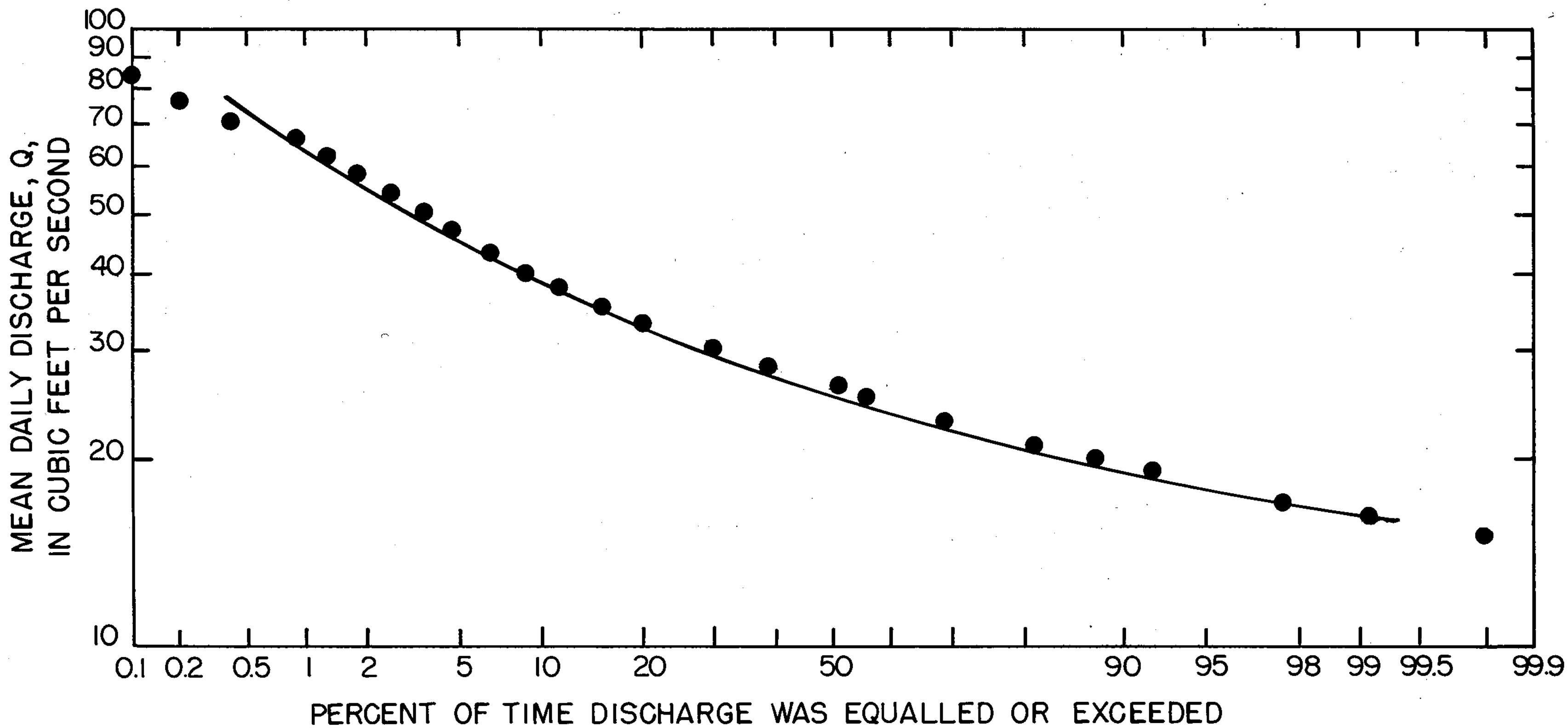


Figure 5.-- Flow-duration curve for site A-1; water years 1966-1977.

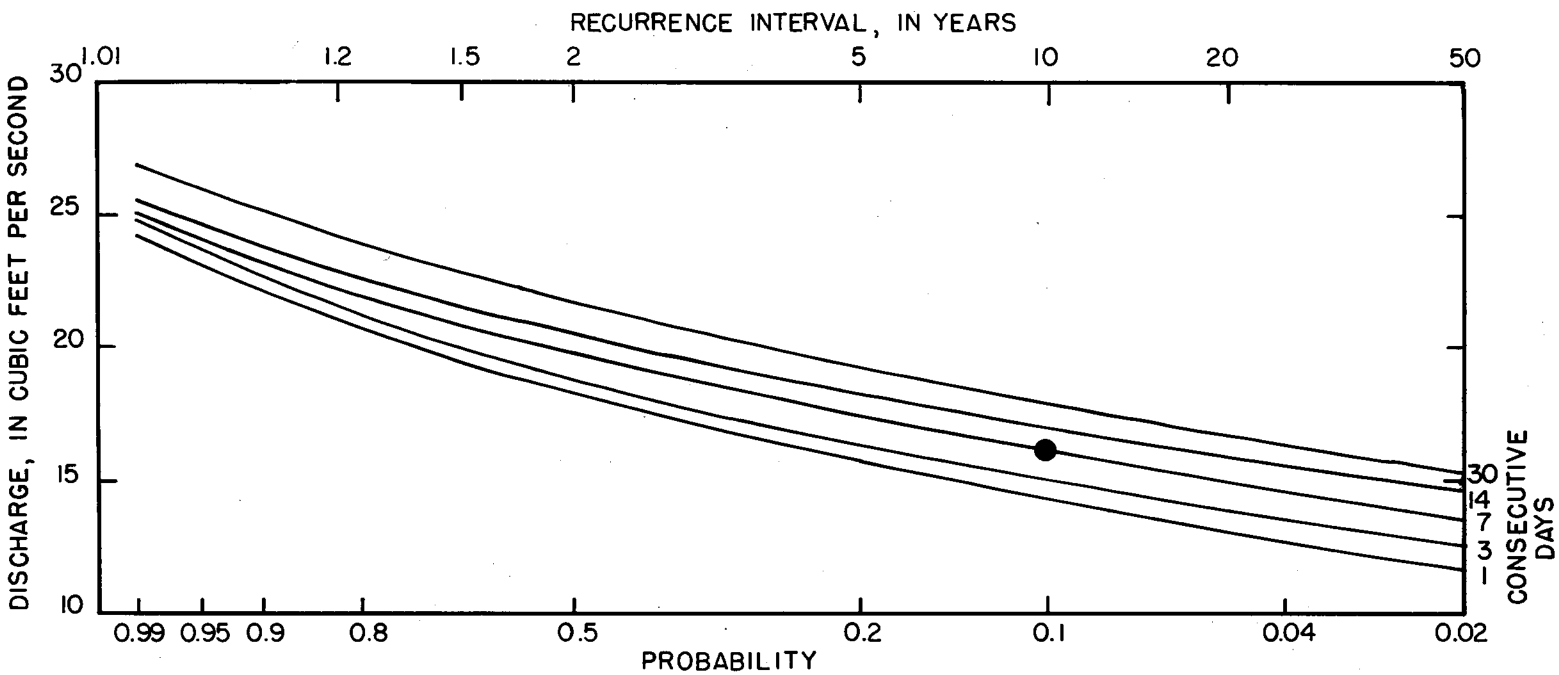


Figure 6.-- Low-flow frequency curves for site A-1; water years 1966-1977.

Surface-Water Quality

The water in Oyster Creek is typically low in pH, nutrients, and dissolved solids. Below the reservoir at site A-3, sodium and calcium are the most abundant cations and chloride is the most abundant anion. Above the reservoir, sulfate content increases, making sulfate and chloride the most abundant anions. Table 1 lists the mean, maximum, and minimum values of the chemical, physical, and biological characteristics monitored periodically at site A-1 from 1966 to 1977.

Dissolved solids concentration ranged from 18 to 42 mg/L with a mean of 28 mg/L, and specific conductance ranged from 31 to 61 µmhos/cm (micromhos per centimeter at 25° C), with a mean of 41 µmhos/cm. The mean concentrations of the major cations, including calcium, sodium, magnesium, and potassium, were all 3.0 mg/L or less, and the two major anions, sulfate and chloride, had mean concentrations of 4.7 and 5.6 mg/L, respectively. These concentrations are low compared with other values reported for the Pinelands region (Rhodehamel, 1970, p. 20).

Nutrient concentrations are also very low in Oyster Creek. Total nitrogen concentrations ranged from 0.02 to 0.36 mg/L, with a mean of 0.15 mg/L and nitrate-nitrogen averaged 0.03 mg/L. The mean concentration of total phosphorus was 0.01 mg/L, with 9 of the 28 samples recording 0.00 mg/L.

Dissolved oxygen levels were high in Oyster Creek, ranging from 70 to 94 percent of saturation, with a mean concentration of 8.7 mg/L. The ranges of pH from 3.9 to 5.8, dissolved aluminum from 0.08 mg/L to 0.5 mg/L, and dissolved iron from 0 to 0.37 mg/L are characteristic of surface water in the Pinelands (Rhodehamel, 1970). The levels of color, ranging from 2 to 85 units, and total organic carbon, ranging from 1 to 29 mg/L, are caused by humic acid and other organic acids and are also typical of streams in the region. The concentrations of fecal coliform and fecal streptococci bacteria, which indicate fecal contamination and the possible presence of pathogens, were generally low. Mean fecal coliform and fecal streptococci bacteria densities were 8 and 29 colonies/100 ml, respectively.

The mean concentrations of bicarbonate, 0.8 mg/L, and alkalinity, 0.5 mg/L, illustrate the low-buffering capacity of the water in Oyster Creek. This low-buffering capacity allows large and swift changes in pH after the addition of small amounts of acidic material.

The uniformity of water quality in Oyster Creek over the years is shown by the narrow range between the maximum and minimum values of most constituents. The quality of water along the main stem of Oyster Creek is indicated by the results of chemical analyses from sampling sites throughout the basin listed in table 2. The values of several constituents tended to be slightly higher in the upstream reaches of the main stem (sites A-10, A-15,

Table 1.--Mean, maximum, and minimum values of water-quality characteristics for site A-1, Oyster Creek near Brookville, New Jersey, water years 1966-77.

[Results in milligrams per liter, except as noted. Numbers in parentheses indicate the number of analyses.]

	Mean	Maximum	Minimum
Temperature, ° C (133)	12.6	27.0	1.0
Specific conductance, μmhos/cm (51)	41	61	31
Color, units (27)	16	85	2.0
pH, units (75)	4.5*	5.8	3.9
Total hardness (42)	6.0	29	3.0
Bicarbonate (34)	0.8	5.0	0
Alkalinity (34)	0.5	4.0	0.0
Acidity (as $CaCO_3$) (10)	17	40	0
Silica (13)	5.5	7.0	3.3
Calcium (42)	1.2	3.0	0.5
Magnesium (42)	0.6	1.3	0.2
Sodium (37)	3.0	4.5	1.9
Potassium (37)	0.5	2.0	0.2
Sulfate (47)	4.7	8.8	2.1
Chloride (43)	5.6	8.6	3.7
Total nitrogen (22)	0.15	0.36	0.02
Nitrate nitrogen (37)	0.03	0.25	0.00
Organic nitrogen (20)	0.12	0.33	0.00
Total phosphorus (28)	0.01	0.05	0.00
Aluminum (6)	.23	.50	.08
Dissolved iron (8)	.17	.37	0
Dissolved manganese (9)	.02	.10	0
Diss. solids [Residue @ 180°C] (38)	28	42	18
Dissolved oxygen (41)	8.7	12	6.6
Oxygen saturation, percent	81	94	70
Total organic carbon (51)	6.2	29	1.0
Fecal coliforms, colonies/100 ml (33)	8**	920	0
Fecal streptococci colonies/100 ml (21)	29**	360	0

*Median
**Logarithmic means

Table 2.--Chemical analyses of Oyster Creek and tributaries; April 13, 1978, and May 24, 1978

[Results in milligrams per liter, except as noted.]

Site	Discharge (ft^3/s)	Temperature (° C)	Specific conductance (µmho/cm)	Field pH (units)	Dissolved oxygen	Dissolved solids	Total hardness	Ferrous iron	Total iron	Sulfate	Chloride	Total nitrogen
April 13, 1978												
A-1	33	14.0	45	4.4	8.9	31	7	--	0.47	2.8	7.6	0.35
A-2	E 20	15.0	46	4.4	9.6	34	7	--	.57	3.0	7.6	.25
A-10	E 7	17.0	59	4.4	9.9	43	9	--	.65	7.5	8.4	.15
A-15	E 3	13.0	60	4.4	10.0	42	11	--	.48	7.2	9.1	.10
A-20	E 1	12.5	53	4.6	10.3	40	10	--	.74	7.6	7.6	.15
B-1	E 4	12.5	39	4.4	9.2	25	5	--	.47	3.1	6.1	.04
C-1	E 0.01	15.5	67	4.1	10.3	42	10	--	.90	6.7	7.6	.85
D-1	E 1.5	11.0	65	4.2	6.2	42	9	--	.48	7.0	9.1	.18
E-1	E 1.0	11.0	53	4.3	9.6	38	8	--	.29	6.0	4.6	.25
H-1	E 0.2	15.0	60	4.2	10.2	39	9	--	.55	7.5	6.8	.20
May 24, 1978												
A-1	52*	14.5	47	4.2	7.3	--	--	0.13	.19	--	--	--
A-2	65.4*	16.0	45	4.3	9.1	--	--	.08	.22	--	--	--
A-10	1.8**	18.0	54	4.3	8.6	--	--	.10	.48	--	--	--
A-20	--	16.5	50	4.5	8.3	--	--	.14	.18	--	--	--
B-1	E 12	15.5	57	4.0	8.6	--	--	.11	.18	--	--	--
C-1	--	15.0	55	4.1	8.4	--	--	.11	.16	--	--	--
E-1	--	14.0	62	4.0	7.8	--	--	.05	.09	--	--	--
F-1	E 0.5	15.0	85	3.9	7.0	--	--	.33	.56	--	--	--
H-1	--	18.5	66	4.3	7.0	--	--	.34	.58	--	--	--

* - Samples taken during rapidly rising stage
** - Sluice gate closed, lake filling
E - Estimated discharge

and A-20) than in the lower reaches (sites A-2 and A-1).

The results from the April 13, 1978, sampling show that between sites A-20 and A-1 sulfate decreased from 7.6 to 2.8 mg/L, total iron decreased from 0.74 to 0.47 mg/L, dissolved solids decreased from 40 to 31 mg/L, dissolved oxygen decreased from 10.3 mg/L to 8.9 mg/L, and specific conductance decreased from 53 to 45 μmhos/cm. The only constituent which increased in the downstream direction was total nitrogen, which increased from 0.15 mg/L at A-20 to 0.25 mg/L at A-2 and to 0.35 mg/L at A-1.

The most significant downstream decrease in concentration was that of sulfate. Above the reservoir, at sites A-10, A-15 and A-20, sulfate was measured at between 7.2 and 7.6 mg/L. Below the reservoir, at sites A-1 and A-2, sulfate was measured at 2.8 and 3.0 mg/L, respectively. Sulfate reduction by bacteria in the organic muds at the bottom of the reservoir was probably responsible for the observed decrease in sulfate below the reservoir.

Concentrations of water-quality parameters were more variable in the tributaries to Oyster Creek than in the main stem and reflected the source of the tributary. Tributaries draining swampy areas, such as tributaries C and F, tended to have higher concentrations of total iron and total nitrogen, and lower pH than tributaries draining upland areas, such as tributary E.

Ground-Water Quality

The ground water in the Oyster Creek basin has higher concentrations of many constituents than the surface water. Table 3 lists the results of chemical analyses of water from the two Oyster Creek observation wells (wells 1 and 2) and the two Waretown observation wells (wells 3 and 4). The pH of the ground-water samples ranged from 4.9 to 6.5. Specific conductance ranged from 35 to 141 μmhos/cm, bicarbonate from 0 to 46 mg/L, and chloride from 4.1 to 11 mg/L, with the highest values of each measured in well 1. Well 1, which is in the swamp muck deposits adjacent to Oyster Creek, also contained the highest concentrations of dissolved solids, ammonia nitrogen, and dissolved and total iron. These high concentrations are the result of the decomposition of organic matter within the swamp deposits.

Water from well 2, which taps the Cohansey Sand directly beneath the swamp muck deposits, had lower concentrations of most chemical constituents than water from well 1. Dissolved solids were 41 and 58 mg/L in water from well 2, compared with 78 and 99 mg/L in water from well 1, and ammonia nitrogen was 0.01 and 0.32 mg/L in water from well 2, compared with 0.54 and 1.5 mg/L in water from well 1. Of the four wells sampled, water from well 2 had the lowest concentrations of total organic carbon (4.2 mg/L), dissolved iron (0 mg/L), bicarbonate (0 mg/L), sodium (2.3 mg/L), and magnesium (0.2 mg/L), but had the highest measured concentration of organic nitrogen (0.61 mg/L).

Table 3.--Chemical analyses of ground water in the vicinity of Oyster Creek

[Results in milligrams per liter, except as noted]

	Oyster Creek observation wells				Waretown observation wells		
	Well 1	Well 1	Well 2	Well 2	Well 3	Well 3	Well 4
Date	12-05-74	11-05-75	12-05-74	11-05-75	10-23-61	01-20-77	03-15-62
Temperature (° C)	3.3	13.6	9.8	12.6	14	11.2	12
pH (units)	6.5	6.2	6.2	4.9	5.8	6.1	5.9
Specific conductance (μmho/cm)	124	141	79	50	35	--	51
Dissolved solids	99	78	58	41	23	24	40
Total hardness	48	35	28	5	6	4	12
Calcium	16	12	10	1.8	.8	1.0	2.9
Magnesium	2.0	1.2	.8	.2	1.0	.6	1.2
Sodium	7.0	5.1	4.0	2.3	4.0	4.7	3.4
Potassium	1.8	.9	1.8	1.1	.8	.6	2.5
Bicarbonate	46	35	28	0	5	6	6
Sulfate	7.7	7.9	6.5	7.5	0	.9	10
Chloride	9.1	11	6.3	4.8	7.6	8.9	4.1
Ammonia (as N)	1.5	.54	.32	.01	--	.01	--
Nitrate (as N)	.05	0	.06	0	.05	.10	0
Organic nitrogen	.10	.22	.61	.14	--	.06	--
Phosphorus	.02	.01	.02	.01	--	--	--
Total Organic Carbon	12	12	7.2	4.2	--	14	--
Dissolved iron	1.5	5.7	0	.06	--	.44	--
Total iron	--	8.8	--	.53	.10	4.0	.81
Total manganese	--	.12	--	.02	0	.01	.10

Note: Well 1 taps swamp (Holocene) deposits
Wells 2 and 3 tap the Cohansey Sand
Well 4 taps the Kirkwood Formation.

Water from well 3, which also taps the Cohansey Sand, had the lowest specific conductance (35 µmho/cm), dissolved solids (23 mg/L), sulfate (0 mg/L), and potassium (0.6 mg/L). One sample from well 3 contained 0.10 mg/L of total iron, while a second sample contained 4.0 mg/L, of which 0.40 mg/L was dissolved iron.

Well 4, tapping the Kirkwood Formation, was sampled once. This sample had moderate levels of dissolved solids (40 mg/L) and total iron (0.81 mg/L) compared with the other ground-water samples. Water from well 4 showed low concentrations of chloride (4.1 mg/L), bicarbonate (6 mg/L), sodium (3.4 mg/L), and nitrate (0 mg/L), but had the highest measured concentration of sulfate (10 mg/L).

Precipitation Quality

Precipitation was collected in the Oyster Creek watershed for more than 7 months and samples were analyzed at 1 to 3-week intervals. The results of the analyses were studied to determine the extent precipitation affected water chemistry. The results of these chemical analyses are listed in table 4. All samples reflect the cumulative rainfall, snowfall, and particulate fallout for the period of collection.

Likens (1976) and other investigators found a trend towards increasing acidity in rainfall in the northeastern United States. The rise in rainfall acidity is attributed to an increase of sulfur dioxide and nitrous oxides in the atmosphere as a result of combustion of fossil fuels. The minimum pH value expected of rainwater in equilibrium with atmospheric carbon dioxide is 5.6 (Likens, 1976, p. 29). Thus, any rainfall pH values below 5.6 are influenced by other chemical constituents. The pH of rainfall samples collected at Oyster Creek ranged from 4.2 to 7.0, with four of the samples having pH values of 4.6 or less.

The chemical composition of rainfall on Oyster Creek was variable. Chemical composition of rainfall is dependent upon wind direction, proximity to the sea, and surrounding land use and industrial activity. Most constituents measured in rainfall at Oyster Creek had concentrations on the order of those in the surface water. Sulfate, calcium, nitrate and organic nitrogen, and phosphorus were all present in rainwater in concentrations close to surface-water concentrations, indicating that precipitation represents a major source of these constituents to the watershed. Concentrations of other ions, including potassium, sodium, magnesium, and chloride, were generally lower in rainwater, although individual samples of each were higher than the average stream concentration. Rainfall may represent a significant source of these ions, depending on atmospheric conditions. As an example, during the period January 12 to 27, 1977, 39 mg/L of sodium was measured in rainfall, a much higher concentration than any measured in surface water over the period of record. An onshore wind carrying a sea-salt spray may have been responsible

Table 4.--Chemical analyses of precipitation at the Oyster Creek rain gage near Brookville, New Jersey

[Results in milligrams per liter, except as noted]

Period of composite sample	Rainfall (inches)	pH (units)	Specific conductance (μmho/cm)	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate	Total Hardness
Sept. 2-14, 1976	(1)	--	237	--	--	--	--	--	14	--
Sept. 14 - Oct. 7, 1976	(1)	7.0	112	--	--	--	8.3	--	13	--
Oct. 7-27, 1976	5.2	5.5	27	0.9	0.5	1.5	3.0	2.4	5.2	4
Nov. 23 - Dec. 14, 1976	.6	--	50	1.0	.4	1.8	3.0	4.4	5.8	4
Dec. 14 - Jan. 4, 1977	1.0	4.4	53	5.2*	.0	.3	.2	1.7	11	--
Jan. 4-12, 1977	3.0	--	54	--	--	--	--	6.1	7.6	--
Jan. 12-27, 1977	(1)	4.6	181	1.1	.3	39	.7	--	8.4	4
Feb. 25 - Mar. 11, 1977	(1)	4.2	95	3.6	1.4	3.8**	--	5.2	15	15
Mar. 11-18, 1977	1.4	--	20	1.0	.3	.6	.2	1.4	3.4	4
Mar. 18-25, 1977	1.8	4.4	23	1.4	.3	1.3	.2	1.7	2.5	5
Mar. 25 - Apr. 8, 1977	2.0	--	43	1.6	1.5	1.1	.2	2.4	4.3	10

	Ammonia-N	Nitrate-N	Organic Nitrogen	Kjeldahl Nitrogen	Total Ortho-Phosphate	Dissolved Phosphorus
Mar. 18-25, 1977	0.12	0.21	0.08	0.20	0.03	0.01

(1) Missing record
* Estimated value
** The value represents sodium plus potassium, by calculation.

for the high sodium level in rainfall during this period. The sodium concentration in rainfall was lower than the corresponding stream concentration for all other sampling periods.

DISCUSSION

Acidity and pH in Oyster Creek

The quality of the stream water in Oyster Creek is dependent on the quality of the precipitation and ground water which feed it. Ground water has a higher pH and higher concentrations of alkalinity, bicarbonate, and iron. The iron in most natural ground water, and probably in the ground water near Oyster Creek as well, is in the reduced ferrous state. As the ground water enters the surface environment and is exposed to the atmosphere, the reduced ferrous iron undergoes oxidation and hydrolysis to ferric hydroxide, according to the following equation (Langmuir, 1969, p. 3):

$$2Fe^{++} + O_2 + 5H_2O = 2Fe(OH)_3 + 4H^+ \qquad (1)$$

For every two equivalents of ferrous iron reacted, four equivalents of hydrogen ions are produced. If the iron concentration is high and the water is poorly buffered, these hydrogen ions can significantly decrease the pH. The complete oxidation and hydrolysis of 1.0 mg/L of ferrous iron in pure water would produce a theoretical pH of 4.4; hydrolysis of 5.0 mg/L would drop the pH to 3.7. Well-water samples contained dissolved iron concentrations as high as 1.5 mg/L to 5.7 mg/L, which could, after hydrolysis, cause substantial decreases in the pH of the water after it enters the surface environment. This is probably the mechanism by which the pH of ground water is reduced as it discharges into Oyster Creek.

Drainage from swampy areas into the stream also adds acidity, particularly during runoff periods. Low pH levels within swamps and bogs are the result of several physical and chemical processes that liberate hydrogen ions (Ruttner, 1974, p. 223-224). The decomposition of organic matter produces carbon dioxide and dissolved humic acids, both of which cause acidic reactions. Low pH levels within bogs are maintained by the adsorption of bases by peat colloids. The living <u>Sphagnum</u> membrane and the peat itself have the ability to adsorb the bases from dissolved salts, releasing acids. This property enables the bog to maintain equilibrium, even with the addition of alkaline waters.

The chemical factors described above are possible causes for the decrease in stream pH as Oyster Creek flows downstream. Figure 7 illustrates this trend of decreasing pH values downstream for the fall and winter months. Each curve represents the profile of pH measured along the creek during 1 day. The pH values consistently decreased downstream, with the highest pH occurring

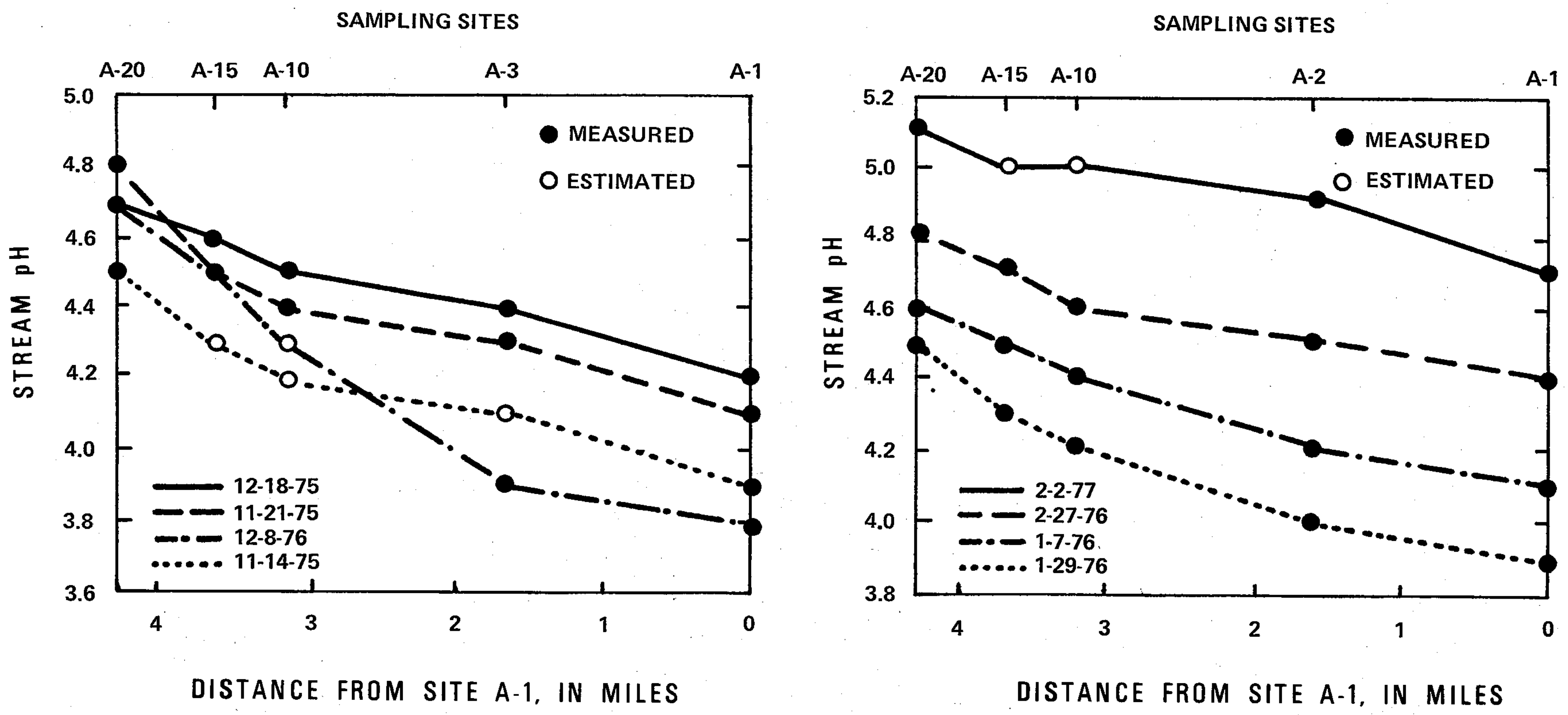


Figure 7.-- Profile of pH values along the main stem of Oyster Creek; 1975-1977.

at the uppermost sampling site, A-20, and the lowest at the gaging station, site A-1.

The pH profile in Oyster Creek during rainfall-runoff periods was consistently lower than that during dry-weather periods, as shown by the pH curves for November 14, 1975, December 8, 1976, and January 29, 1976, all days with above normal discharge. This suggests that runoff is a factor in causing drops in pH.

The pH profile for February 2, 1977, on the other hand, was significantly higher than those during normal dry weather periods. During the winter of 1977, exceptionally cold temperatures caused the ground and swamps surrounding the creek to freeze, leaving ground water as the only source of streamflow. The frozen swamps were not inputting organic acids and other acidic materials to the stream, causing a rise in pH throughout the basin. The stream pH during this cold weather period was lower than the ground-water pH, however, and continued to decrease in the downstream direction, indicating that some chemical reactions producing hydrogen ions were still occurring.

Stormwater runoff and drainage from swamps and bogs are major causes of the occurrence of excessively low pH in Oyster Creek. Frequency curves of pH were developed for swamp pH and stream pH. Figure 8 compares the pH frequency curves of Oyster Creek at site A-1, with the adjacent swamp sampling site. These curves show the percentage of time a given pH was equalled or exceeded. In the stream, where the median pH was 4.5, the pH was 4.0 or higher 94 percent of the time. The swamp pH, which had a median value of 3.8 and a minimum of 3.3, was 4.0 or higher only 33 percent of the time and was consistently lower than the stream pH at site A-1 by half a pH unit or more. The difference between stream and swamp pH is particularly noticeable during warm weather, when the evaporation and transpiration in the swamps concentrate the acidity.

The difference in pH in the streamflow and the water in nearby swamps is maintained during dry-weather because of the limited interchange of water between stream and swamp. Large storms, however, cause more complete mixing of stream and swamp waters, and the addition of the low pH swamp water to the stream reduces the pH level of the poorly buffered and already acidic streamflow to below 4.0. It is these large and rapid drops in pH which are most damaging to aquatic life.

The relationship between storms and low pH is illustrated in figure 9, which charts daily mean discharge and daily minimum pH from April through September 1975. The discharge hydrograph and pH graph are approximate mirror images, with peak discharges coinciding with low pH levels. All the large pH drops occur during fairly large hydrograph peaks, although correlations between pH and stream discharge do not show a direct relationship between the two.

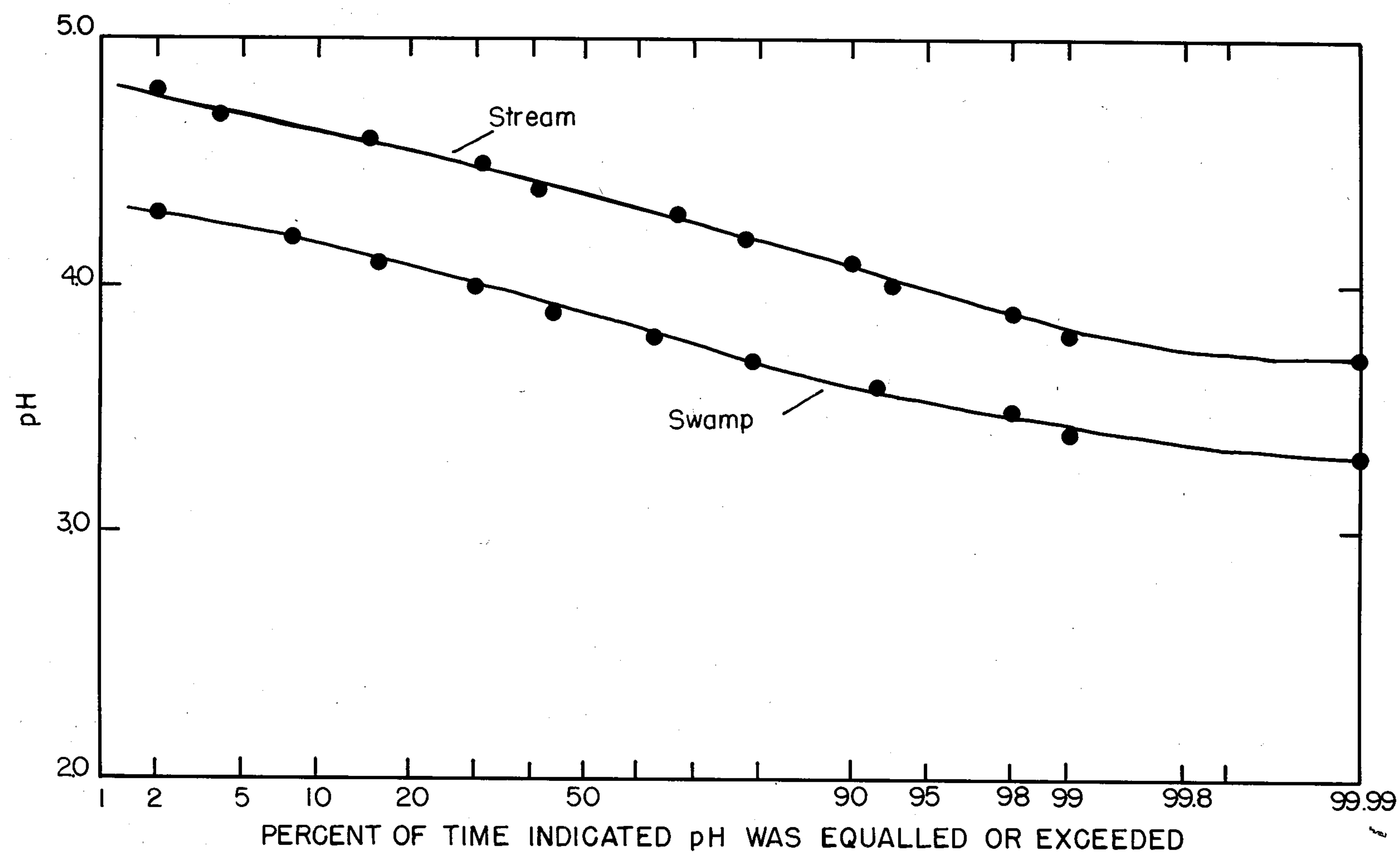


Figure 8.--Graph showing pH frequency curves for site A-1 and adjacent swamp sampling site; 1974-1977.

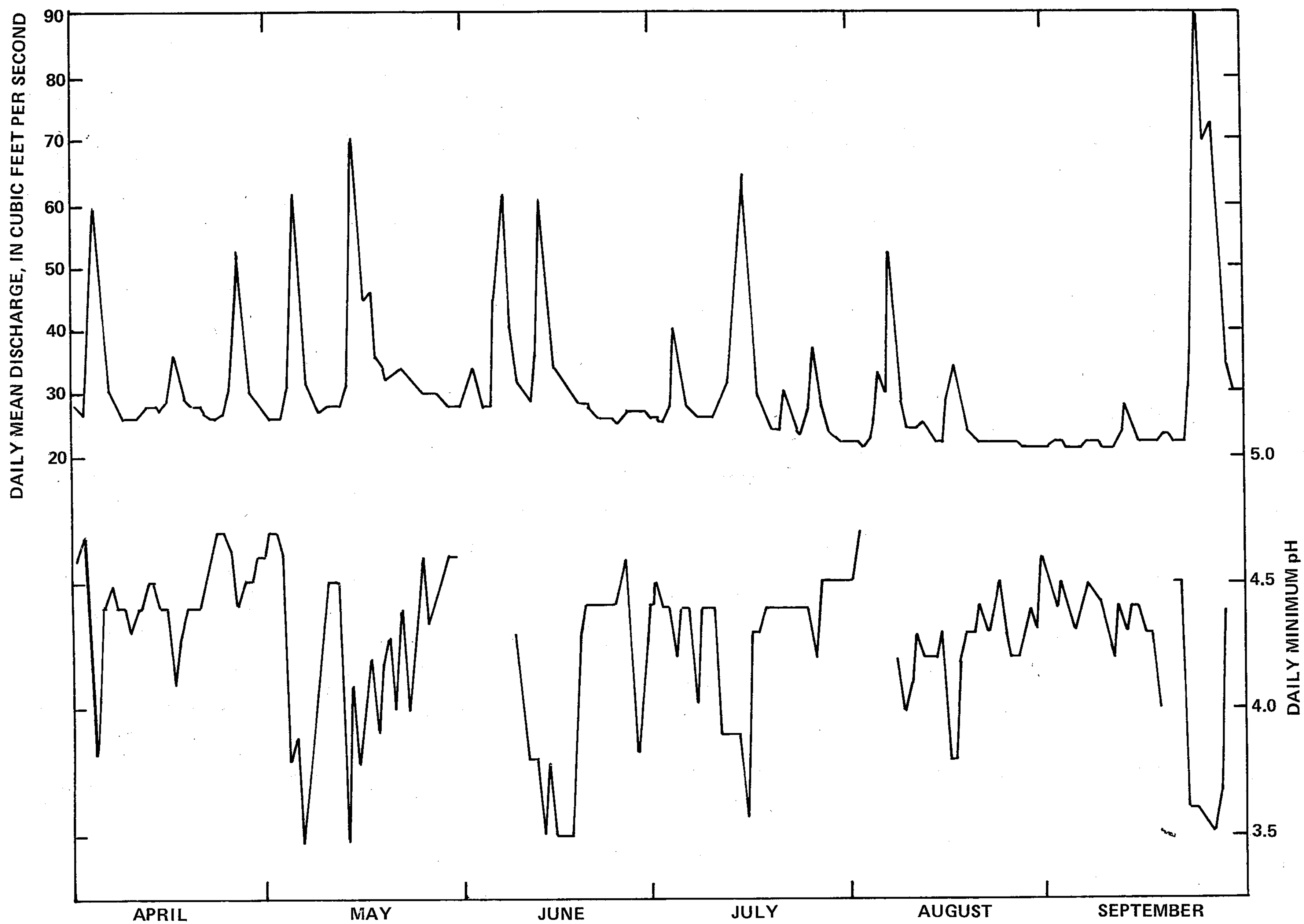


Figure 9.--Graph showing daily mean discharge and daily minimum pH at site A-1; April through September 1975.

During the period shown in figure 9, there were eight distinct periods during which daily minimum pH values below 4.0 were recorded and at least five when minimum pH approached 3.5.

Figure 10 shows the changes in pH recorded by the water-quality monitor during four storms in 1975 and 1976. All four plots have a characteristic drop in pH as the stream stage begins to rise, although they differ in the sharpness of the drop and in the minimum pH attained. Each curve exhibits a small pH drop at the beginning of the storm hydrograph, after which the pH rises slightly before dropping again. These smaller pH drops are caused by the initial runoff following a heavy rainfall.

Most rainfall does not directly run off the Oyster Creek watershed. It infiltrates into the sandy soils or is stored within swampy areas. As the water table rises due to the large volume of recharge, ground water will be discharged to the stream at an increasing rate, causing a gradual rise in the storm hydrograph. The rising stream stage and increasing water levels within swamp areas bring the two into increasing contact. Eventually, the stream flows over its shallow banks and into the swamps and mixes with the more highly acidic swamp water, causing a rapid drop in stream pH. This flushing appears to occur at about a stream gage height of 4.3 to 4.5 ft at site A-1, and a discharge of approximately 40 ft^3/s. This is the point during most storms at which a rapid pH drop begins, as shown in figure 10.

Assuming that the flushing of acidic swamp water is the major cause of the high acidity during periods of increased discharge, then the minimum pH level in the stream should approach the pH of the swamp water. For each storm shown in figure 10, the minimum stream pH was compared with the latest pH measured at the swamp sampling site before the storm. Three out of four times, the minimum stream pH after the storm did approach the pH measured in the swamp. Only during the September 1975 storm did the stream pH decrease to a lower level than the pH of the swamp. This may be due to the fact that the swamp water was sampled at only two sites close together and therefore may not be totally representative of the large swamp area within the basin. Additional swamp areas could not be sampled because of their poor accessibility.

Effects of Acidity on Trout

Research by Pyle (1957) has shown that brook trout are capable of surviving in waters of New Jersey where pH is as low as 4.3. This level is in close agreement with minimum pH values of trout survival determined in other studies and listed by McKee and Wolf (1963, p. 236). Trout survival is seriously impaired at low pH, although the exact physiological causes have yet to be defined. Packer and Dunson (1970 and 1972) suggest that the death of brook trout at low pH levels (2.0 to 3.5) is due to an inhibition of oxygen uptake, a reduction in blood pH, and, to a lesser extent, a loss of body sodium. Jones (1964, p. 109)

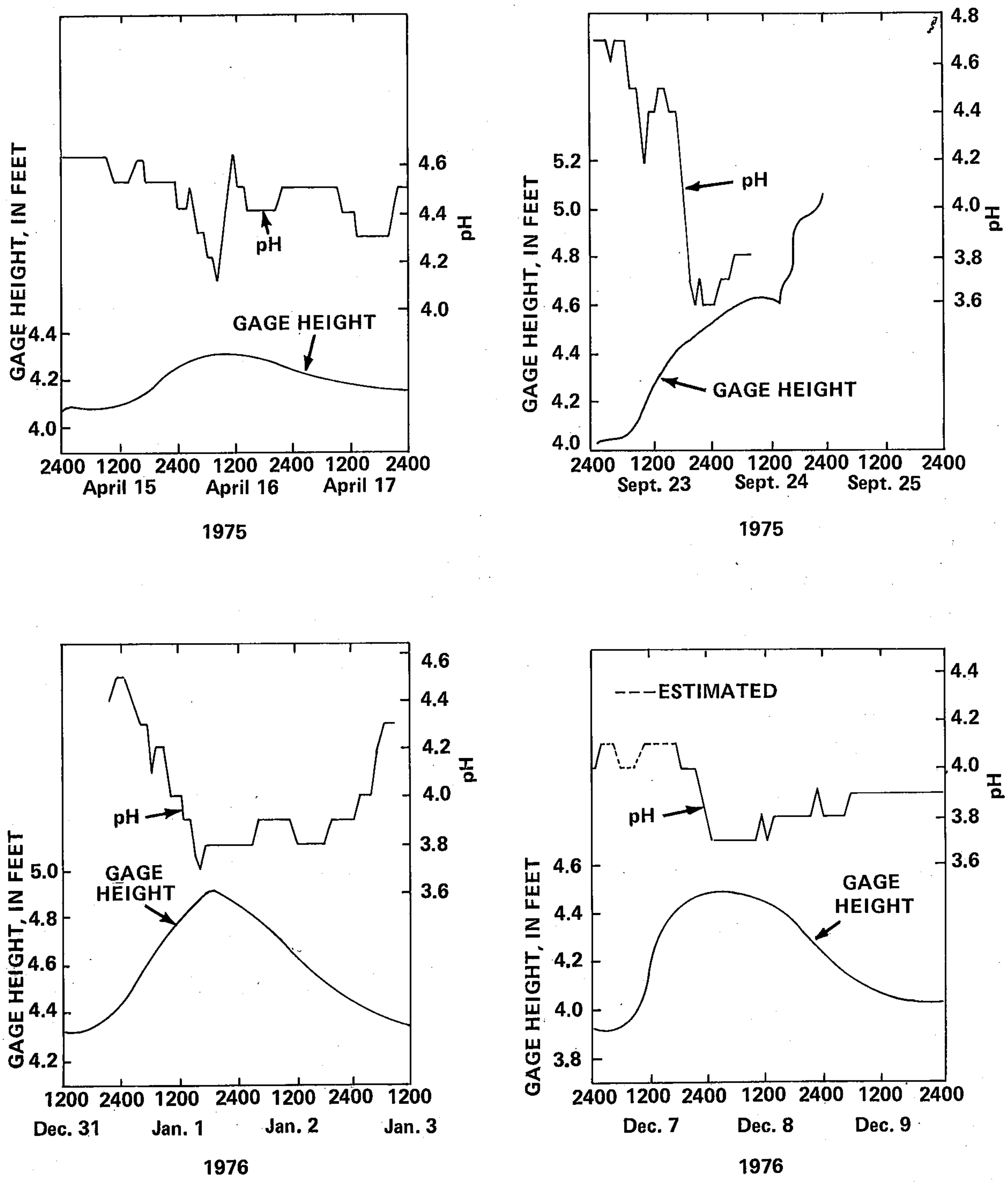


Figure 10.--Graphs showing hourly gage-height and pH at site A-1 during four storms; April 1975 to December 1976.

summarizes experiments by Ellis which show that acidic water kills fish by causing precipitation of the mucus on the gills and coagulation of the gill membranes. Larsen and Olsen, in research cited by Jones (1964, p. 170), found that trout-fingerlings placed in acid iron-polluted water died of asphyxiation because the slime of their bodies was coagulated with an accumulation of iron ochre (ferric hydroxide). The pH range tolerated by fish may be affected by other factors, including temperature, dissolved oxygen, prior acclimatization, and the concentrations of various anions and cations. Work cited by McKee and Wolf (1963, p. 236) indicates that fish that can tolerate pH values as low as 4.8 will die at pH 5.5 if the water contains 0.9 mg/L of iron.

Oyster Creek, which has excellent water quality in most respects, is subject at times to very low pH. In one 6-month period between April and September 1975, pH of 3.5 were recorded on five occasions, whereas values below 4.0 were recorded eight times over the same period. At these low pH levels, water begins to have a toxic effect on fish, particularly in combination with the moderately high concentrations of dissolved and suspended iron often found in Oyster Creek. The exact cause of death of the trout stocked in Oyster Creek was not determined, however.

An indirect effect of low pH upon fish populations may be the limiting of the available invertebrate organisms consumed by trout. A qualitative survey of aquatic invertebrates in the Oyster Creek basin on August 24, 1978, found no larval insect forms or benthic invertebrates at the site of the gaging station (Site A-1); although some aquatic adult stages, including water striders and other water bugs, were found. Also, no benthic invertebrates were seen at Site A-2, which had a muck and gravel substratum similar to that at Site A-1. Farther upstream, however, at Sites A-10 and A-15, large numbers of benthic invertebrates were sampled, including larvae of caddisflies, dragonflies, and mayflies. As pH generally is higher in the upper reaches of the creek, conditions there may be more favorable for invertebrates. The absence of benthic invertebrates in the lower reaches of Oyster Creek does not preclude a viable trout population, however, as Hynes (1970, p. 367) states that trout take great quantities of food at the water surface, and in the summer 40 to 50 percent or even more of their food is terrestrial insects.

SUMMARY

Oyster Creek and its tributaries were sampled for pH and other chemical, biological, and physical characteristics to aid in developing management techniques for brook trout in acidic streams and lakes. The chemical and biological measurements indicate that the overall quality of water in Oyster Creek is good, with the exception of extremely low pH (3.5-5.8) and low-buffering capacity (mean total alkalinity 0.5 mg/L). Mean concentrations of dissolved solids and dissolved oxygen were 28 and 8.7 mg/L, respectively, and mean specific conductance was 41 μmho/cm.

Concentrations of nitrogen and phosphorus were low. Total phosphorus ranged from 0 to .05 mg/L, with a mean of 0.01 mg/L. Dissolved iron and manganese averaged 0.17 and 0.02 mg/L, respectively.

The concentrations of most chemical constituents in the main stem of Oyster Creek decreased slightly from the upstream sites to the downstream sites, with the exception of total nitrogen, which increased downstream. The water quality in the tributaries varied greatly, according to the source and flow rate of the tributary.

Concentrations of chemical constituents in ground water were generally higher than those in surface water. The maximum concentrations of ammonia-nitrogen and dissolved iron in ground water were 1.5 and 5.7 mg/L, respectively. Specific conductance was 35 to 141 μmho/cm, and dissolved solids were 23 to 99 mg/L.

The normal acidic conditions (pH 4.0-5.0) in the Oyster Creek basin are the result of natural processes. The creek is fed largely by slightly acidic ground water. Oxidation and hydrolysis of iron and the formation of humic acids and other acids by the oxidation of organic materials may combine to increase the acidity of this ground water as it enters and flows through the stream. These acid-producing reactions are prevalent within the swamp areas, where pH is typically half a unit or more below those in the creek.

Rapid drops in stream pH to below 4.0 are caused by the mixing of poorly buffered stream water and more highly acidic swamp water during heavy runoff.

Acidic water of pH less than 4.0 has killed brook trout in several experiments. The exact physiological changes associated with the death of fish at low pH have not been determined, although research indicates an inhibition of oxygen uptake, a reduction in blood pH, a loss of body sodium, and coagulation of mucus and gill membranes in fish at low pH levels.

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